THE RELATIVE LEGIBILITY OF THE SMALL LETTERS.

BY E. C. SANFORD.

When everybody reads, and some do scarcely anything else and the amount to be read increases daily, it is obviously of the highest importance that reading should be made as easy and rapid as possible. If any device of paper or ink or type can shorten the time and lessen the labor even by a very little, the aggregate advantage will far outweigh the trouble, especially as saving is to be expected at the same time in the more important matter of wear and tear on the organs employed. The problem is to get the greatest amount of matter with the greatest ease in reading on the least space; or, as it has been phrased, to get the greatest legibility to the square inch. The problem has many factors, for the result depends on the tint and quality of the paper, on the ink, on the length of the lines and the space between them, on the size of the letters, their proportions, the relation of their light and heavy lines, their distances from one another, and on still other details, all of which are small in themselves, but none of which can be neglected when the question is one of the maximum clearness. And all must be mutually adjusted with reference to the demands of taste and economy. To the typographical factors, Dr. Javal, an eminent French oculist, has devoted considerable study and experimentation, an

interesting account of which, by himself, is to be found in the *Revue Scientifique*.[1] The only other experimental research, so far as I know, which touches the question, is one by Dr. James McKeen Cattell, first published in Wundt's *Studien*;[2] the work upon the letters being incidental, however, to an extended psychometrical study. Dr. Javal tested legibility by the distance at which the letters could be read; Dr. Cattell by the number of times a letter was read right or wrong when seen for a very small fraction of a second through a narrow slit in a falling screen.

In the experiments about to be described the single factor of the letter forms was taken out for study. A standard alphabet has been carefully tested to determine the order of legibility of the letters among themselves, and the groups of letters most liable to mutual confusion. The order of legibility thus reached shows on the one hand what letters are most in need of improvement, and on the other, in a certain degree, upon what clearness depends. The distance and time tests have both been applied, though with apparatus somewhat different from that used by the investigators just mentioned. The distance experiments will be described first.

Apparatus and Methods used for the Distance Tests.

For accurate measurement of the distance a simple instrument was used. It consisted of a wooden rail 3.4 m. long placed before the subject, slanting downward at an angle of about 14°. One end came a little

---

[1] *Revue Scientifique*, 1881, Vol. XXVII, p. 802.

[2] *Philosophische Studien*, 1885, Bd. III, H. 1, S. 94. The same is to be found in abridged form in *Brain*, Vol. VIII, p. 295; and the part on the letters in *Science*, Vol. VII, p. 128.

below the chin of the subject when seated, the other a few inches from the floor. To the upper end was fastened at right angles a vertical board about four inches wide, and a rough profile cut in this gave support to the chin and forehead of the subject and kept his eye in a fixed position. A little wooden car sliding on the rail carried an upright of wood to which was fastened a movable disk of cardboard. The letters were pasted without natural sequence near the edge of the disk, and a black cardboard screen pierced by a square hole of 2 cm. on the side was tacked on in front. By turning the disk the letters could be shown one after another through the hole at a height above the rail equal to that of the eye. A millimeter scale pasted along the top of the rail marked the distance.

The standard letters chosen were Snellen optotypes of the size D=1.25.[1] The height of the short letters is about 1.8 mm. and of the long about 2.2 mm. The following alphabet is in type resembling that used for experiment: **a b c d e f g h i j k l m n o p q r s t u v w x y z.** The letters were cut from the optotype book with some margin about them, and neighboring letters shaved away so as to leave each letter standing alone and free from the possibly confusing shadows cast at the edge of the paper when cut near the letter. A few experiments were made upon letters from *Mind*, but for them this precaution was not taken, and the screen used was white instead of black. There was nothing in the setting of the letters on the disk to show which extended above and below the alignment except the remnants of a faint pencil line, which, as will appear in the tables, had little or no effect.

[1]The formula D=1.25 means that the letters are of such a size that the short ones subtend an angle of 5′ at a distance from the eye of 1.25 m.

The illumination was as far as possible that of the clear sky. Some alphabets were taken with light of less than full intensity ; but in almost every case the illumination was the same for the whole of each, so that no error is to be expected in the *relative* determination aimed at.

Of the five subjects, four were graduate students and one a recent doctor of this University. They will be designated by the initials A, B, H, J, and M. H and A are quite far sighted, J moderately so, B may be taken as normal, while M is near sighted, but by the use of his glasses read at distances not very different from those of B.

Legibility for distance was measured in two ways. By the first the letter-disk was set at fixed distances and the whole alphabet shown in general twice or more at each distance. The first distance used for H, M, and B was 1.5 m., and this was increased 10 cm. at a time till a distance of 3.2 m. was reached. The distances were then correspondingly decreased till all the letters could be read. J went only down the scale from 1.6 m. to 3.2 m., and A only up from 3.2 m. to 1.8 m., after having first seen the letters at a comfortable reading distance. In taking the record the subject announced, when the letter was shown, what he supposed it to be, and his answer was recorded ; if he were in doubt he gave the possible letters in what he supposed to be the order of probability, unless all seemed equally probable. In the case of H one other answer was allowed for letters that had become indistinguishable by distance, namely: "One of the small letters ; no preference." This method gives us the order of legibility as shown by the number of times each letter was rightly or wrongly named, all distances being taken

together, and at the same time the letters with which each is most confusable when the confusion is caused by distance. These things appear in the following tables.

RESULTS BY THE FIRST METHOD FOR DISTANCE.

TABLE I.

Order of Letters as shown by Percentages of Right Answers.

m 90.9	v 71.0	x 63.0	n 46.2
w 88.1	k 70.9	a 60.8	e 46.2
f 84.4	b 70.4	i 60.6	c 45.1
p 84.3	y 70.4	l 58.6	o 44.9
q 80.9	h 69.9	u 55.2	z 34.1
r 78.7	d 68.3	s 53.0	
j 77.6	g 68.2	t 46.5	

The numbers in Table I are percentages on a total number of answers varying from 291 to 313. The full records of H, M, A, and J were included, and that of B in going down the scale from 1.5 m. to 3.2 m. In the cases of doubt where the answer contained several letters, the letter recorded as having the greatest probability was counted as if it had stood alone, on the ground that if but one letter had been allowed in the answer that would have been the one. Where no difference in probability was recorded, the answer, even when containing the right letter, was counted wrong.[1]

[1] The latter half of B's record was excluded because it shows a large proportion of answers in certain fixed forms: for example, "b or h" for both b and h, or "c or e" for c, e, and o. This came, as B himself recognized later, from his having unintentionally ceased when the letters were almost indistinguishable to report a preference for the one or the other, the single answer being made for all letters of a certain degree of indistinctness. There were five of these forms pretty well marked; "b or h," "c or e," "i or l," "u or n," and "x or z," ease of pronunciation seeming to have fixed the order of letters in the answers, except the last. The part of B's record included in Table I was also, though to a less degree, influenced by the same tendency, and the result would have been, if the answers had

TABLE II.

Showing the Confusability of the Letters as tested by Distance.

m	29	w 52, u 24, n 10, a 7, * 7
w	34	v 53, u 12, m o 6, * 24
f	49	r 37, l 20, j 16, t 10, i 6, * 10
p	36	r 44, y 17, j q 8, g t 6, * 11
q	54	g 30, z 19, s x 7, c n u 6, * 20
r	49	v 22, f 12, s t y 8, c o 6, * 29
j	57	l 25, f 21, i 18, t 12, c 5, * 19
v	61	r 33, t 11, e 8, q 7, * 41
k	88	x 34, h 12, g 11, a 10, b 8, d 6, * 18
b	77	h 45, k 14, a u 10, n 8, * 12
y	69	p 61, r 29, f 6, * 4
h	91	b 51, k 40, * 10
d	69	a g 22, n 9, k o 7, * 33
g	73	r 12, t 10, f 8, a 7, d j o s u 5, * 36
x	96	n 19, z 15, a 9, k w 7, g m o 6, * 24
a	100	u 16, n 14, s 13, k 12, b 9, h 8, e 6, z 5, * 17
i	117	l 58, t 21, j 9, * 12
l	113	i 39, j 36, t 7, f 5, * 12
u	115	a 18, z 12, x 9, n v 8, s 7, g 6, b k o 5, * 17
s	105	n 14, c r 12, i 10, e 9, o v 8, a u 7, * 13
t	129	i 40, s 9, d 8, x 7, l 6, * 31
n	144	a 41, z 12, b 6, h 6, * 35
e	144	c 40, s 11, v 8, r 7, u 6, * 27
c	146	e 34, o 23, u 10, v 9, * 24
o	151	c 34, e 23, a 13, u 11, n 5, * 14
z	144	e 19, s 17, a 16, t 9, o 8, c 8, g 6, * 17

Table II will not be found to tally exactly with Table I, because B's record was here entirely excluded and because all the alternates in cases of doubt are counted in, the object here being solely to show the confusables and their proportionate confusability. The figures as before are percentages, except in the column next the

been counted as those of the other men, to give a disproportionate number of right answers to the letter standing first, and a disproportionate number of errors to that standing last. By way of correction, one half of the number of fixed answers for each letter has been applied positively or negatively as necessary to the letters affected, except to the letter o where one third was used instead. The addition of B's record so corrected to that of the other observers changed the order of letters only as follows: k advanced from behind d to before b, and u and s, q and r, and o and e changed places. The letter d would perhaps have stood a little higher in the list had not B suffered a certain inertia in answering "x or z" for it; this error was not, however, such as could be safely corrected.

letters, where is given the actual number of errors and alternates upon which the percentages are calculated. Letters appearing in the record less frequently than five per cent of these numbers have been regarded as scattering errors and only the percentage of them all together has been given. Scattering errors are indicated by the asterisk. No great weight is attached to many of the confusions which occur more than five per cent of the times, because of the possibility of habit in answering, as explained in the note above.

The Second Method of Distance Determinations.

This method was intended partly to be a check upon the first and partly to fix more accurately the distances at which the letters are just legible. The plan here was to set the car at the bottom of the rail, or beyond the point at which the letter in question could be distinguished, and to have the subject draw it slowly toward him till he was sure what the letter was. Two distances were generally recorded; one the point at which the subject first thought he knew the letter; the other, the point at which he was certain. H, J, and M were tested in this way with the Snellen letters; H and M going over the alphabet ten times each, J five times. Early in the experimentation B and M were thus tested with the letters from *Mind*, B giving eight alphabets, M four.

Owing to the differences of individual eyesight, this method does not give results that can be gathered up in a single table, but the following tables for the single subjects, together with the curves which accompany them, give some means of comparison.

Results by the Second Method for Distance.

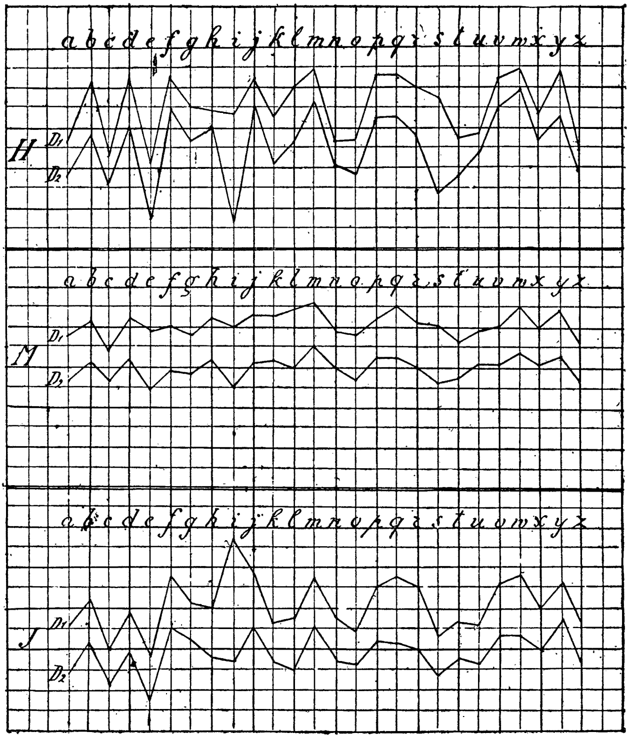
TABLE III.

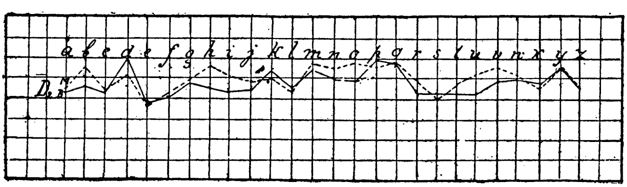
Showing the Distances in Meters at which the Snellen Letters were recognized with certainty by H, M, and J.

	H.		M.		J.	
	D_2.	M. V.	D_2.	M. V.	D_2.	M. V.
a	1.877	.095	1.326	.122	1.185	.153
b	2.400	.100	1.564	.147	1.560	.117
c	1.788	.113	1.336	.151	1.064	.087
d	2.539	.074	1.593	.166	1.449	.078
e	1.364	.104	1.223	.114	.820	.049
f	2.727	.260	1.450	.110	1.745	.047
g	2.310	.188	1.396	.118	1.628	.111
h	2.473	.136	1.594	.146	1.394	.075
i	1.324	.073	1.262	.139	1.345	.251
j	2.768	.203	1.551	.169	1.722	.107
k	2.076	.151	1.574	.160	1.353	.121
l	2.333	.321	1.499	.176	1.251	.081
m	2.842	.267	1.758	.188	1.778	.131
n	2.049	.116	1.538	.101	1.366	.079
o	1.912	.053	1.334	.114	1.322	.066
p	2.605	.130	1.622	.132	1.588	.116
q	2.628	.124	1.626	.148	1.591	.226
r	2.365	.176	1.505	.139	1.508	.140
s	1.662	.130	1.327	.156	1.181	.048
t	1.856	.068	1.374	.175	1.358	.045
u	2.153	.098	1.545	.171	1.329	.084
v	2.725	.119	1.561	.114	1.703	.125
w	2.953	.206	1.678	.147	1.707	.150
x	2.339	.069	1.553	.124	1.524	.070
y	2.639	.182	1.642	.141	1.852	.122
z	1.940	.116	1.317	.100	1.287	.142

In Table III the columns headed D_2 give the average distances, expressed in meters, at which the letters were recognized with certainty; those headed M. V. give the mean variation of the single quantities entering the averages after which they stand.[1]

[1] The mean variation is found by averaging the variations of the single quantities from the mean, no account being taken of whether the variation is positive or negative.





See note, p. 435.

In these curves the ordinates are averages of distances drawn to a scale of about $\frac{1}{70}$. The curves marked D_1 are those for the distances at which the subject would first venture an answer and did actually answer correctly ; those marked D_2 are for the distances at which he knew the letter with certainty, and correspond to the columns similarly marked in Table III. For the letters from *Mind* only the certainty distance was recorded. The separation of the curves D_1 and D_2 for any letter indicates the distance through which the letter had to be drawn to bring the subject from a minimal degree of confidence to certainty. It is the zone in which the letter would in general be guessed correctly. In the case of H this zone would probably have been wider for some of the most legible letters but for the fact that he read them with a certain degree of confidence at the extreme limit of the apparatus.

COMPARISON OF THE RESULTS OF THE TWO METHODS FOR DISTANCE.

To facilitate comparison, the orders of legibility for distance arrived at by the two methods are here given :

From Table I,

m w f p q r j v   k b y h d g x a i l   u s t n e c o z

From Table III,

H. w m j f v y q p   d h b r x l g u k n   z o a t c s e i
M. m w y q p h d k   b v x j u n r l f g   t c o s a z i e
J. y m f j w v g q   p b x r d h n t k i   u o z l a s c e

Letters from *Mind*,

B. d p q m y k n w   o g v x h b j l i a   t u z r s c f e
M. m q o p h b n v   y u d i w k g j r t   x a c z l f s e

It will be seen that there is a general agreement in the orders ; but at the same time there are some

differences. A perfect agreement is hardly to be expected. As between the order of Table I and those of Table III, a part of the difference is caused by difference in the method of computation. Table I being made from the united answers of a whole series of distances, letters like i which have a wide zone in which they tend more or less to be correctly named would have the advantage of letters like u and n which have a narrower one. For Table III, however, width of zone counts nothing at all. Furthermore, it is not impossible that Table I is still slightly affected by fixed answer forms too little marked to be open to correction; and both tables would be affected, and probably in different degrees, by fixed letter preferences, if any such existed in the minds of the subjects.

The differences of H, M, and J among themselves are in part the result perhaps of optical differences, and in part of differences in the points by which the letters were recognized. H and M, as they have told me, fixed upon the white place between the stem and dot of the i as the sign by which to distinguish it from l, and to see this clearly were obliged to bring the letter quite near; but J trusted to the general smallness of the letter, and this proved at least for him a reliable sign, for he recognized i farther and named it correctly a greater proportion of times than H or M. Something similar may have happened with other letters, though the question has not been investigated.

Another factor which operated probably to a certain extent in both the methods was, strange as it may seem, defective memory of the alphabet. Something more will be said of this in another connection, but it will suffice to say here that all the letters do not seem to be all the time equally present in the mind of the

subject. One or another may fall out for a time and so not be considered in deciding how to name a barely visible letter.

Between the orders for the Snellen letters and those for the letters from *Mind* we may look for differences due to the forms of the letters, the latter being relatively longer and slimmer and having the upward and downward extensions of the long letters about one half the height of the small letters instead of about one fourth as in the case of the optotypes. Taking H's order for the Snellen letters, which is in substantial agreement with that of one or the other of his colleagues for nearly every letter, and B's for the letters from *Mind*, it will be seen that in the latter d, p, q, k, n, o, g and i are advanced; while f and j are set far back, and in a less degree r, w, u and v. The increased length accounts for the advancement of the long letters. The long letters not advanced, except f and j, are b, h, l and y. But y stands already near the head of the list and the other three may be kept back by possible confusions; b and h with each other, and l with i. The i is improved by the increase in height, having more space between its stem and dot. The n and o perhaps are favored by finer lines and larger internal areas of white, but why u should not then be advanced too remains unexplained. The f and j, and perhaps the v, r and w, owe their low position to their narrowness. The orders for B and M are at variance between themselves, and the only value of the latter is the slightly confirmatory one of its agreement with that of B in the advancement of i and the setting back of f, j and w.

So much for disagreements; let us now consider the concurrences. If we divide each series into

three groups of eight, ten, and eight each, we may call those in the left group good, those in the central group fair, and those in the right group poor letters. All the orders from the Snellen letters agree in setting w, m and q in the left, b and x in the central, and z, o, c, s and e in the right group. If we now add to each group those letters that fall in it three times in four we shall have the left group increased by j, f, v, y and p, the central by d, h, r, l, g, k and n, and the right by a and t. Two letters, u and i, occur twice in the central and twice in the right group, but the u's in the central stand third and sixth from the line of division, those in the right section first; the i's, on the contrary, stand only first and second in the central section, but seventh and eighth in the right. We may then fairly put i among the poor letters and u among the fair. This gives us as the final classification w, m, q, p, v, y, j and f as good; h, r, d, g, k, b, x, l, n and u as fair, and a, t, i, z, o, c, s and e as poor.

Relative Legibility and Confusability by the Time Tests.

Methods and Apparatus.

The time test was of the same nature as the first distance test. A certain fraction of a second was chosen, generally between two and six one-thousandths, and the letters were each shown several times for that interval, then another fraction of a second was chosen and the showing repeated and so on. The degree of legibility appears as before in the percentage of correct answers, all the stages being taken together.

The exhibition of the letters for such short periods requires more complicated apparatus than that employed for distance. After some trials of other ar-

rangements the letters were finally set in a dark box and the length of their exhibition controlled by the length of an artificial illumination.[1] The critical point, however, in all such experiments is the measuring machine, and various plans were tried till a happy suggestion of Professor Hall's led to the working out of the instrument used. This has proved in some respects so satisfactory that I shall venture a rather full description of it.

The illumination is controlled by the passage of corresponding notches in overlapping disks driven by a pendulum. The pendulum swings between T-shaped iron columns cast in one piece with the heavy base upon which they stand. The pendulum rod is a steel bar two feet long, an inch and a quarter wide and a half inch thick, and the bob is a lens of lead nearly six inches in diameter. Together they weigh about twenty-three pounds. The shaft upon which the pendulum swings is set in bearings that allow the pendulum to turn clear round over and over. On the same shaft, fastened securely to the pendulum rod, is a brass cogwheel eleven and three-quarter inches in diameter and a half an inch thick. This wheel has 144 teeth and works on each side into a little wheel, less than an inch in diameter, having twelve teeth. The little wheels therefore make twelve turns to every complete turn of the large one. The shafts of the little wheels

[1] The apparatus used by Dr. Cattell has the merit of great simplicity. But the width of the slit in the falling screen through which the letter appeared seems to have been less in the most part of his experiments than the height of the long letters of the type used. Moreover, where room must be left for the movement of a screen before the letter, the eye cannot be perfectly adjusted for distance. In Dr. Cattell's apparatus this was only 3 mm., but under favorable circumstances binocular double images can be gotten from objects 3 mm. apart at a distance of eight or ten inches. The aim of the arrangement adopted was to avoid these difficulties.

run through the ends of the arms of the forward T-column and end in flat brass disks four inches in diameter. The overlapping disks that regulate the illumination are clamped upon these by other free disks of brass which go on in front and are held in position by nuts that screw on to posts in the middle of the first mentioned disks. The overlapping disks are thirteen and three-quarter inches in diameter and of cardboard. As the pendulum swings these two disks move in a direction contrary to its motion and so both in the same direction. Their overlapping sides, therefore, the left side of the right disk and the right side of the left, move in opposite directions; when one moves up, the other moves down, and *vice versa.*

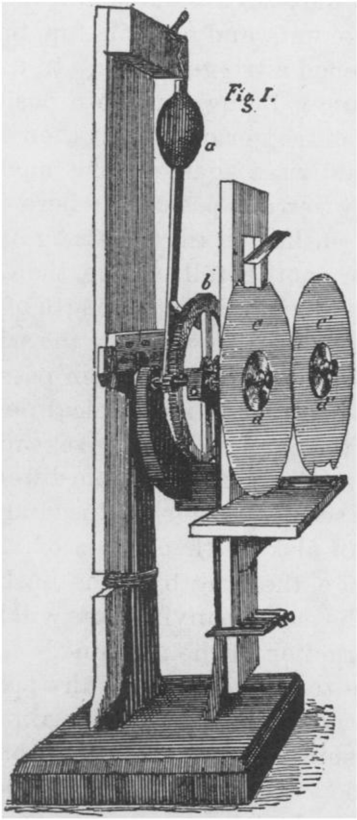
By means of two inclined mirrors the light is caused to pass from behind toward the overlapping edges of these disks. Every time, therefore, that the notches in the disks coincide, the light will shine through for a length of time depending on the width of the notches and the rate of the disks. For every complete circuit of the pendulum, however, there would be twelve coincidences and twelve flashes of light, were not all but the shortest one cut off by another disk behind these two. This is about seven inches in diameter and is moved at the same angular rate as the pendulum by a set of two and a half inch gears, one on the main shaft of the pendulum and one on the shaft of the disk. A notch in its edge allows the light to pass during that portion of the circuit of the pendulum in which the shortest coincidence of the notches of the large disks occurs, and cuts it off at all other times.

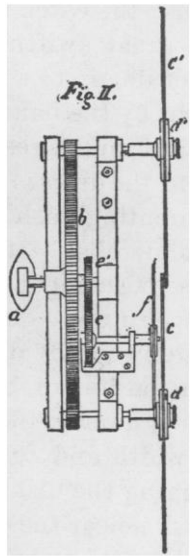
The rate of the pendulum, and with it the angular rate of the disks, is kept constant from one fall to another by letting the pendulum start each time from

a fixed point. For this purpose a stout plank is fastened to the rearward column, and near its top, but a little to one side, is fastened a trigger catch. In using the machine the pendulum is brought up into position against the catch and the trigger pulled; it then falls with great swiftness and rises again on the opposite side of its arc to a nearly vertical position, where it is caught by the hand and pushed on till it rests again on the catch and is ready for another fall. Since, then, the rate of the disks is the same each time, the length of the illuminating flash can be varied by varying the width of the notches. It would no doubt have been possible to use permanent disks with some mechanical device for opening and closing the notches, or to have reached the same end by dropping the pendulum from different points on its arc, but it seemed better in this study to make a number of sets of disks with notches of varying width and to change the length of the flash by changing the disks. The accompanying cuts will help to make clear the construction of the machine.[1]

The width to be given to the notches for any particular fraction of a second is measured by making a tuning-fork write upon smoked paper fastened upon the brass disk mentioned above as clamping the cardboard disks. The fork is attached to the armature of an electro-magnet and the pendulum can be made to close and open the circuit in its fall. The fork is thus made to write for a little more than a single turn of the disk, the turn chosen being that in which falls the illuminating flash. In this way it was found that this turn of the disk is made in less than 0.07 of a second, and that an angle whose arc measures ten eighths of an inch on a circle thirteen inches in diameter is passed over in about one five-hundredth of a second; or, since the overlap-

[1] See pages 418 and 435.





ping edges of the disks move in opposite directions with equal speed, notches of this width in both will pass one another in one one-thousandth of a second. From this as a unit any required interval may be laid off; for the rate of the disks is sensibly constant for several consecutive thousandths of a second. A certain error was to be expected from the play of the wheels when the pendulum crossed the lowest point of its arc. This might have been avoided by making the coincidence

of the notches come before the pendulum reached that point, but in the first tracings taken the error was hardly noticeable. The extreme variation from all causes in that part of the turn covered by the notches, as estimated from 81 tracings taken at different times during the experimenting, was about one part in eighteen. The instrument might, perhaps, be criticized on the ground of its noise, but this is a constant factor and the subject soon becomes completely oblivious to it.

The dark box was of simple construction, about fifteen inches square and nine deep, and was set obliquely before the machine. The letters were pasted as before on a cardboard disk, and were immediately behind a centimeter square opening in a black cardboard screen at the back of the box. The disk could be turned from behind through a hole in the box. The place of the letter was indicated by pinholes pricked near it; at first by four, later by three. The illuminating flash entered the box by a cardboard tube and fell on the letters at an angle of about 40°, while the subject looked perpendicularly upon them at a distance of sixteen inches. A certain quantity of extraneous light entered the box in various ways, sufficient often to make the white square about the letter dimly visible to eyes thoroughly accustomed to the dark, but never, of course, sufficient to disclose the letter.

The light used for the illuminating flash was from a free-burning gas-jet re-enforced by a plane reflector. The total distance traversed by the light in reaching the letters was about three and one half feet, and in its course it was twice reflected. Its intensity was therefore not great, but that is of little consequence in the present instance. A more serious disadvantage was

the quivering of the flame, which was an undoubted cause of variation in the reading of the letters, but the number of exhibitions of each letter makes its effect inconsiderable in the final result.

As before, the Snellen letters were those most thoroughly tested; the tables for them rest upon a basis of two hundred exhibitions of each letter. A second set of letters of nearly the same dimensions, but of somewhat different shape (heavy faced old style), and including as extra forms the small capitals A, E, L, and T, and a long s, was exhibited eighty times.

The following alphabet is in type like that used, but smaller:

a	b	c	d	e	f	g	h	i
j	k	l	m	n	o	p	q	r
s	t	u	v	w	x	y	z	

The small capital A was made by inverting a v; the E had its backward extensions trimmed away; and the T, L, and long s were made from parts of other letters, the latter from the tails of two j's.

The subjects were doctors and graduate students of this institution, except C, who is a boy about fourteen years old. The number of alphabets furnished by each was as follows: For the Snellen letters, C, 5; H, 38; J. H, 18; J, 23; L, 45; M, 26; S, 21; U, 24; and for the other alphabet, H, 11; J. H, 12; J, 12; L, 11; M, 12; S, 13; U, 9. The lengths of time for which the letters were exhibited varied with the individual; records taken with H, for example, from 0.0013s. to 0.004s. are included in the table for the optotypes, and with J from 0.002s. to 0.006s.[1]

[1]Absolute exactness is not attached to these times, though they are approximately correct. It is sufficient for the purposes in view that the time should be the same for each letter of the alphabet. As measured by the width of the notches the figures are probably slightly too small; but, on the other hand, while the notches are passing each

RESULTS BY THE TIME METHOD.

Table IV corresponds to Table I, except that the percentages of wrong answers and of the times when no answer was ventured are added.

TABLE IV.

Snellen letters:

	Right.	No Answer.	Wrong.		Right.	No Answer.	Wrong.		Right.	No Answer.	Wrong.
m	82	7	10	f	58	6	36	o	39	17	43
w	73	1	25	b	52	11	36	u	38	13	48
d	67	7	25	l	49	8	42	a	35	15	49
q	66	5	28	i	48	15	36	n	34	8	58
v	63	7	29	g	47	13	39	e	33	20	46
y	62	5	32	h	47	9	43	s	27	21	51
j	61	12	26	r	43	11	45	c	26	14	60
p	61	7	31	x	42	16	41	z	23	19	57
k	61	7	32	t	39	15	45				

Old style letters:

	Right.	No Answer.	Wrong.		Right.	No Answer.	Wrong.		Right.	No Answer.	Wrong.
m	90	2	7	j	56	6	37	a	32	21	46
w	82	6	11	r	55	7	37	t	31	16	52
p	79	1	20	l	54	10	36	f	30	20	50
q	74	10	16	o	52	14	34	s	29	24	47
v	70	7	22	n	45	14	41	x	29	21	50
y	67	5	27	i	42	16	41	z	27	24	49
k	64	2	34	g	41	22	36	c	26	29	45
b	61	16	22	h	40	10	50	e	14	24	62
d	56	17	26	u	37	16	46				
ſ	45	9	46	L	22	31	46	E	5	26	69
A	39	15	46	T	6	20	74				

other, the chink through which the light shines opens from nothing to the full width of the notches and then closes to nothing again, thus giving at one end of the interval a phase of increasing and at the other of decreasing light, which would shorten by a small amount the time for which the letter is really visible.

Dr. Cattell found with his apparatus and letters of the same size that half of the alphabet was read correctly with an exposure of from 0.0011s. to 0.00135s.; in this study it was found that from 0.0017s. to 0.004s. or 0.005s. was necessary for an equal proportion of correct

Table V corresponds to Table II in calculation and arrangement.

TABLE V.

Snellen letters:

a	116	n 18, s u 14, e 11, g 6, c z 5, * 24	n	130	a 34, u 14, q 6, h 5, * 41
b	85	h 24, a 11, n k 8, o 5, * 41	o	105	e 32, c 26, a 9, q 7, * 27
c	140	o 25, e 24, r 6, * 44	p	70	y 17, g 14, q 10, b e n o 6, * 36
d	57	a 28, g n 7, l m q u 5, * 37	q	69	d g 14, o 13, a 9, b c n s u 6, * 20
e	113	o 25, c 16, d 8, g 7, v s 5, * 33	r	100	y 14, f g 12, p t v 8, i 7, z 5, * 26
f	84	l 21, i t 14, r 13, j 8, g 6, * 27	s	121	a 19, e 14, o z 11, g 8, * 37
g	90	a s 17, z 12, k 9, d 8, x 6, * 32	t	112	i 28, l 18, f 11, j 9, r 8, y 5, * 21
h	101	b 44, k 13, a 10, n 8, * 26	u	109	n 21, a 19, e 9, c 7, * 43
i	87	l 39, t 17, j d 9, * 25	v	71	r 25, y 18, e w z 6, * 39
j	62	l 47, d 11, i 10, g 8, y 6, * 18	w	55	v 16, n r 9, a g u 7, e m s 5, * 27
k	69	h 20, g 12, x 10, a 9, y 7, n 6, * 36	x	91	k z 20, n 12, a 10, g 7, * 32
l	97	i 44, j 19, t 8, d y 6, * 16	y	71	g p 15, r 14, q 11, v 8, f 7, * 28
m	28	o w 18, a e 14, k n x 7, * 14	z	124	s 23, g 17, a 12, x 8, k 7, * 34

Old style letters:

a	46	n 17, u 11, o 9, c d e s x 7, * 30	n	37	p 19, a 16, u 11, o 8, b q r s t 5, * 19
b	23	h 26, k p 13, t u 9, * 30	o	33	e 27, c 15, a b p 9, x z 6, * 18
c	40	e 15, r 10, g k t 8, a n u E 5, * 33	p	17	g E 18, q 12, b e i l r t u w ſ 6
d	21	a 19, j 14, g l u 10, * 38	q	16	o 19, c s E 13, d e g r u v A 6
e	53	c 24, r 9, n s z 8, u 6, * 38	r	34	f 35, i v 18, l 6, * 24
f	41	i 24, l 17, ſ 15, j 12, t 10, * 22	s	45	a 16, n 13, c z 11, e x 9, g h 7, * 18
g	34	n 15, z 12, a h E 9, d g q x 6, * 24	t	45	i 27, l 22, f 11, j 9, k 7, * 24
h	50	b n 32, p 8, * 28	u	48	n 19, c o 15, e 10, b 8, z E 6, * 21
i	37	l 30, j 27, t 24, f 11, d 8	v	23	w 22, o 17, y 13, c e q 9, * 22
j	35	l 40, ſ 26, i 20, * 14	w	10	E 30, a 20, m n o u v 10
k	37	h 22, t 16, b l s 8, f g l 5, * 22	x	45	z 18, k 13, a 11, s 9, v 7, * 42
l	31	i 35, j 29, t 16, f z 6, * 6	y	25	v 28, p 20, n u 8, * 36
m	8	w 50, e n z L 13	z	44	x 20, s v 9, g r y 7, * 41
A	42	a 38, e 12, c n 7, * 36	ſ	40	j 40, f 28, l 15, i t 5, * 8
E	61	a 11, m 10, s z 8, g k r 7, * 42	T	64	r 55, v 8, l t y 6, * 19
L	41	t 27, b 22, * 51			

answers. Two reasons for this difference are clear, namely, that the illumination used here was much fainter, and that the retinas of the subject were each time before the illumination in an approximately unstimulated condition (*vide* Wundt, *Phys. Psych.* 3 Aufl. II, 267). There is, moreover, a peculiarity in Dr. Cattell's apparatus which may render the figures less comparable than might at first appear. The slit in his falling screen had to be 1.3 mm. wide to pass over a given point in 0.001s. The long letters are, however, 2.2 mm. high, and the length of time from the instant in which the top of the letter first became visible to that in which the bottom of the letter ceased to be visible must have been 0.001s. plus the length of time required to pass over the letter, which was about 0.0017s. Any particular point of the letter was therefore seen for 0.001s., but the whole letter was in the process of being seen for 0.0027s.

These tables are subject to the same disturbing influences and therefore to the same criticisms as their parallels for distance, and as before, some of the confusions represented as possible owe their prominence to individual peculiarities of the subjects.[1]

The order of legibility for time, in spite of some variations, is in substantial agreement with that for distance. For the sake of comparison these are given below, together with that given by Dr. Cattell.

Order for time, Snellen letters,

m w d q v y j p   k f b l i g h r x t   o u a n e s c z

Order for distance, Snellen letters, combined result,

w m q p v y j f   h r d g k b x l n u   a t i z o c s e

Order for time, old style letters,

m w p q v y k b   d j r l o n i g h u   a t f s x z c e

Order for distance, letters from *Mind*, B's record,

d p q m y k n w   o g v x h b j l i a   t u z r s c f e

Order of letters for time, given by Dr. Cattell,

d k m q h b p w   u l j t v z r o f n   a x y e i g c s.

By a strange bit of perversity several of the worst letters fall in the number of those most frequently used. In a full font of type the eight letters most largely represented are as follows:

e 12000	a 8500	n 8000	s 8000
t 9000	i 8000	o 8000	h 6400

[1] Another test of legibility would be to present the letters to the eye in indirect vision. This is especially worthy of trial because in normal reading the eye does not pass at a uniform rate from letter to letter, but flits from word to word, almost from phrase to phrase, judging many letters in the indirect field. It is hardly probable, however, that it would show results essentially different from those for distance and time. The connection of rapidity in reading and the indirect field has been demonstrated by the experiments of Dr. Cattell, *Mind*, Vol. XI, p. 64.

What Points of Form Help and What Hinder Legibility.

It can be said *a priori* that legibility will be favored by enlarging the size and increasing the differences of the letters. And it is easy to show also that legibility is favored by simplicity of outline and concentration of the differentiations upon one particular. The influence of size is clear from the composition of the left groups in the alphabets of the last section, where it also appears that breadth is as great an advantage as length. With most of the letters breadth is rather more of an advantage, other things being equal, than length, for it gives some visibility to their internal spaces; and Dr. Javal is undoubtedly right in prefering short broad letters to long and narrow ones. The differences necessary to legibility have been neglected by the makers of phonetic alphabets, in their desire to indicate phonetic similarity by similarity of form. If such alphabets are ever to come into general use they will certainly have to be improved in this respect. Simplicity of outline, or what is the same thing, solid areas of black and white, will be found in most of the letters of the left groups. It may even compensate for small size, as is shown by the legibility of v. In accordance with this principle, the ceriphs, or little finishing strokes of the letters, for example at the top and bottom of h and the ends of s and z, should, as Javal recommends, be made short and rather triangular than linear in shape. They are really more important in protecting the tips of the letter from the rounding effects of irradiation than in giving it a finished appearance, and should therefore be as small as possible and yet accomplish that object. When they are too long, as is certainly the case with the Snellen letters, they

easily lend themselves to confusion. The concentration of differentia is well seen in the group b d p q, where each of the letters is made of a straight stem and a loop, the whole difference being made in combining the two. All are very legible letters except b, which suffers from confusability with h.[1] An example of lack of concentration is found in g and a, which have few points in common with other letters and yet are mistaken for many different ones.

The element of size cannot be used to improve the relatively poor letters without at the same time shocking taste and opening the way for new confusions. It is therefore from simplification and emphasis of the points of difference that help is to be expected. In the c e o group, for example, the point of distinction of c and e from o is the gap in the side, and Javal is right in proposing a return to the more open forms of the earlier type-founders. He suggests two forms for e; one like that in the "old style" letters above with the cross line near the top, and one in which the cross line is made longer and more prominent by an oblique position, thus, *e*. It would appear from Table V that the first of these is about as confusable with c as the common form is. The advantage of the wider openings of the c and e appears in the less percentage of confusion with o, as shown by a comparison of the second part of Table V with the first and with Table II. The two forms of the Greek epsilon, ϵ and ε, and an E, made with square corners like the capital to distinguish it from c, suggest themselves as possible substitutes. The result of the tests for the latter is given in the

[1] The difficulty which has made a proverb of "Mind your p's and q's" is the difficulty of naming each correctly, and not that of recognizing their forms as different.

second part of Table IV, where its extreme illegibility is strikingly demonstrated. All the letters added suffered somewhat from ignorance on the part of the subject of their exact form and from a tendency to let them drop out of memory in answering, but E is the worst of the five. In Dr. Cattell's experiments on the capital letters E proved worst of all.

Another group of the poor letters includes a, n, and u. The distinction of n and u from each other and from a ought to be helped by keeping their openings at the top and bottom as open as possible, and the slight advantage shown in this particular by the second half of Table V over the first may be due to the wider openings of the "old style" letters. Dr. Javal points out the curved top of the a as a point of resemblance to n and recommends a form of the first letter found in the Italian manuscripts that furnished the model for some of the early typemakers. In this the top is very small and the loop is relatively long horizontally, giving the letter the appearance at a distance of an inverted r : ɹ. Even in the less exaggerated form which the letter would be given if it were adopted, it could easily be distinguished from u and n; and from s also, with which it has some tendency to confusion. The great legibility of v suggested that its inverted form, small capital ᴀ, might be substituted (after the analogy of c, o, s, v, w, x, and z) for the present a, and it was tested with the "old style" letters. Table V shows a slight advantage for it in spite of the handicap of the added letters. Strangely enough, the letter with which it was most frequently confused was the a-form now in use; had that been omitted it might have stood considerably higher in the list.

Dr. Cattell says that s is "hard to see"; and the

number of times no answer at all was ventured for it, together with the wide scattering of its confusions, show him to be right. Dr. Javal, too, thinks it rather a hopeless case, but suggests the sharpening of its angles as a way of making it approach the legibility of z. In the s of the "old style" alphabet this has been done to a certain degree and the letter made relatively a little larger. As long as the present form is retained something of this kind is probably all that can be done. Tests were made, however, on a long *ſ* with the satisfactory results shown in Table V. The long s that is so much like f should of course be avoided, but great legibility is to be expected from a form that extends both above and below the line; it would at least put confusions with z and a out of the question.

The group with which this form of s is most prone to confusion is the long, narrow group, f, j, i, l, t. Of these f and j are good letters when the projections at the top of one and the bottom of the other are made heavy and long enough, as shown by the superiority of the Snellen f and j over the same letters in the alphabet from *Mind*. It is preferable if the s confusion is to fall anywhere that it should be on these letters rather than on a and z. The other letters of the group are not nearly so liable to confusion with the long s as with each other. Dr. Cattell suggests λ for l and suppression of the dot of the i. Dr. Javal would shorten the t and prolong its cross toward the left (this, however, chiefly to distinguish it from f, the cross of which is to be prolonged the other way); and he would set the dot of the i as high above the stem as possible, at the same time making it heavy to avoid breakage, and thickening the stem to match. The value of Dr. Cattell's suggestion for l is doubtful. The letter suggested

is totally foreign to our Roman alphabet, and very possibly would be confusable with b and h as y is with p. Removing the dot from the i would certainly make it more legible when standing alone, but much more confusable when with other letters in a word. Twice when for a few weeks I had the matter in mind, my attention was called to i's in print accidentally deprived of their dots; in one case l and i together made a tolerable h; in the other the loss of the dot turned "ruin" into "rum." The small capital forms for L and T were put to the test with unsatisfactory results, partly due perhaps to the fact that the letters were made from parts of other letters set together. The t difficulty could probably be solved as Javal suggests, and the distinctive point of the i, the separation between the dot and stem, could be emphasized by making the stem shorter than the rest of the short letters, though this would hardly be tolerated from an æsthetic point of view.

The confusion of x and z and of s and z would be lessened by reducing the ceriphs to the lowest possible limits.[1]

Into the remaining confusions of Tables II and V it is hardly profitable to go, but it may be added as explanatory of some of them that a difference of size was

---

[1] If acceptability is entirely neglected, it is not hard to suggest geometric forms of great probable clearness to replace some of the forms of the present alphabet. A cipher alphabet which fulfils the conditions in a high degree is found on page 291 of the *Revue Scientifique*, Sept. 3, 1887, where it is attributed to the Freemasons, though the same has been shown the writer as once current among the pupils of an American school. The letters are all made from the lines and spaces of the set of crossing parallels used in playing "tit-tat-to" together with an ×; the upper left hand angle giving a, the same with a dot in it b; the next three-sided square standing for c, or with a dot in it for d, and so on. The letters are all made with straight lines and large open spaces. The dotted forms are of course not as good as the empty ones, and some of these are found in developed shape in our present alphabet, but others remain to be utilized if necessary.

sometimes perceived which failed of interpretation; for example, the answer y when r was the letter might be "y minified," or when o was guessed for d or b, "o magnified." Again, confusions of letters which in ordinary print extend, the one above, the other below the line, appear in the tables, but may be safely called impossible in actual reading. It might be questioned, too, whether tables made up for all degrees of distance and time show those confusions most to be feared under ordinary circumstances. But a collation of the errors made at the shortest distances and the longest times with those of Tables II and V shows a substantial agreement for most of the letters, and for most of the remainder the changes are only in the relative importance of the confusions. There is a tendency for unusual ones such as d for j and q, and g for r, to drop out; g shows a good deal of variation; a and s tend at the shorter distances to confuse a little more with each other than with other letters, but for longer times the reverse is the case if there is any difference; x is somewhat more likely to be called z or k, and less likely to be called n; and so with the other letters that show differences in order; but in the main, and especially for the letters most in need of correction, the table represents nearly enough the errors liable to occur in ordinary reading of letters like those tested.

The letters were chosen as being to a certain degree typical and furnishing a fair point of departure for investigating other letter forms, but generalizations from them must be made with caution. To settle finally and in detail just what letter form is to be selected as most legible would require a very long series of tests, in conditions as near as possible to those of normal reading, upon many existing and possible variations of each letter.

Physiological and Psychological Incidents.

The unusual conditions under which the eyes were used in these experiments brought to notice two or three optical phenomena, a description of which will help to explain some of the confusions found in the foregoing tables and may be interesting in itself.

At the longer of the distances used in the tests by distance, the letters appeared as dark grayish dots, and were recognized, if at all, chiefly by their outer configuration. These dots did not seem, however, to maintain one fixed and constant form ; but on the contrary, while the subject strained his eyes to make one out, first one letter and then another would take form in it. This any one can try for himself by setting up a letter at a distance considerably greater than that at which it can ordinarily be read, and studying it intently. It would be extremely interesting to decide where the cause of this shifting and interchanging lies, whether in the apperceptive centres or in the retina. Every one knows the ease with which expectant attention perceives what it expects, and it may be that the variation in the letter dot is only a parallel and index of the movements of attention from one mental letter-image to another as they pass into the focus of memory. On the other hand, it might be in part at least a retinal matter. The average diameter of the cones in the fovea corresponds nearly to an arc of one minute in a spherical field of view; the square letters of the optotypes therefore, at a distance of 1.25 m., lay upon from twenty to twenty-five cones, and at the end of the rail on about four, and the other letters in proportion. Now if these retinal elements undergo more or less rhythmic changes (from fatigue and recuperation or from any other cause),

which are not entirely synchronous among themselves or with those of the other eye, it would give a basis at least upon which the attention could construct the changes of image described. The phenomenon is something like that of binocular rivalry, and like that, waits its final explanation.

In some of the time tests binocular effects were discoverable, but what there was to hinder exact convergence of the eyes it is hard to see. Such answers, however, as $ for t, 9 for b, ♀ for p or q, "a monogram of a and q" for q, "m with four strokes" for m, "two capital A's side by side" for A, show it beyond question, and no doubt some of the answers of w for v and of q for p should be attributed to the same cause. Such answers as the third and fourth would indicate that both eyes do not always see all parts of the letter with equal distinctness.

Another singular thing noticed when the letters were momentarily illuminated points the same way. A part of a letter would sometimes be seen normally solid and black, while the rest of it appeared faint almost to extinction; thus an h would have a solid body like an n, but a stem sketched in outline. In this way probably came the answers of o for q in both parts of Table V, and of n for h and v for y among the "old style" letters. Answers of this kind are to be found in Dr. Cattell's table of confusables in the *Studien*. They are so clear indeed that the conclusion seemed at first unavoidable that the narrow slip used by him had caused guesses to be made when only a part of the letter had really been visible at the instant when the attempt was made to see it. But this clearly cannot be the cause in the present instance. The phenomenon was not confined to the long letters, but cannot so

easily be shown from the table for the others. There hardly seems room here for a psychological explanation; but if for any reason one of the eyes received the whole h form and the other only so much of it as is like n, the different appearance of the stem and body of the letter would not seem strange. But this would require a different excitability of the retinal elements among themselves in one retina or the other, and in so far, if justified, would give a presumption in favor of at least a retinal factor in the variability of the letter-images before mentioned.

With the instantaneous illumination a curious illusion was brought out. As described above, the place of the letter was indicated by a small rectangle or triangle of pin holes showing as bright dots, and the letter itself was seen just behind a square hole in a black screen. When the letter was set accurately at the centre of the square it appeared, with reference to the dots, as it actually was; but when, as sometimes happened, the letter and its dots were turned too far or not far enough, so that the letter stood at one side of the hole in the screen, it was seen as displaced with reference to the dots also, and in the same direction as with the square. Attention to the illusion tended to destroy it, but otherwise it could be repeated almost at pleasure. It seems not to be of binocular origin; at least it has several times been obtained monocularly in a few tests made to try that point. The thing is difficult to account for, and no conjecture will be ventured at present.

It has already been said that unequal recollection of the letters of the alphabet has probably affected the tables given. The temporary dropping out of a letter has several times been noticed, and a few times its

return has been so sudden that the subject has exclaimed that he had been forgetting such and such a letter. The writer himself read d correctly a number of times at rates from 0.003s. to 0.005s., but at 0.006s. named it wrongly the three times it was shown, and only guessed it once in the whole set for any other letter. But a much more marked case was that of M, who, in thirty-five alphabets taken with the Snellen and "old style" letters at intervals from December 29 to the last of January, read c correctly but twice and made it but twice as a guess for some other letter, and during the same period never answered e at all; but on February 11, in three alphabets, taken to be sure with a little longer illumination, he read e correctly three times and guessed it twice for c. He showed no aversion to these letters in the distance experiment.

A certain hindrance to this dropping out of letters, at least for the distance tests, was interposed by the repetition of the whole alphabet; this is shown in the part of B's record omitted. The time being limited in which to take observations with decreasing distances, I thought to shorten the work by ceasing to present a letter as soon as it had been correctly read a certain number of times. At the distance 2.3 m. I omitted, without the knowledge of B, the letters f, g, m, q, r, w, and y. The omission of y had a strange effect on p, which I still continued to give. At 2.4 m. p was rightly named the three times it was shown, but from 2.3 m. to 1.9 m. it was constantly called y, and even at less distances did not escape confusion with that letter. That is to say, we have p, by right one of the clearest letters, mistaken for y, when z, t, n, u, and l were read and a, c, e, i, o, and s the only letters in doubt. The withdrawal of the corrective to the mental y-

form furnished by the actual y, and the dropping of p from the focus of memory, allowed the return of the y-confusion that had attended p at greater distances. The time covered by these experiments was about two hours. These facts make it appear that in the "letter habit" there is a variable factor which would have to be accurately determined before the law of probabilities could be applied to the letter-guessing tests for telepathy and the like.

The effect of practice is evident in the records for both distance and time. H was able to recognize all the letters with certainty at 1.5 m. when he began, and at 1.8 m. when he ended. M. was in doubt about c, e, and o at 1.5 m. when he began; on returning, the letters were brought no nearer than 1.9 m., where he recognized all the letters except c, j, o, and z; the errors for all but o being, however, but one each in seven or eight trials. B's record in general shows something of the same kind. The gain at this point measures the gain in distinguishing the worst letters; the better letters do not show so much, and a few were recognized on decreasing the distances only at a nearer point. The following averages of the distance for the eight alphabets from B's record on the letters from *Mind* show the gain for the alphabet as a whole: 0.935, 0.995, 1.076, 1.010, 1.090, 1.101, 1.240, 1.161. These were B's first trials with the letters. The first six were taken two a day on successive days, the last two after an interval of some weeks; the last is lowered somewhat through a loss of confidence. The table below gives the actual number of right and wrong answers and of the times when no answer was returned for the first twelve alphabets taken by the time method with J. H. The letters were the "old

style," including the five added letters; the time was 0.004s.

Right.	No Answer.	Wrong.	Right.	No Answer.	Wrong.
3	22	6	11	4	16
3	16	12	12	4	15
2	23	6	10	7	14
4	17	10	13	6	12
5	11	15	15	4	12
8	6	17	16	2	13

The first eight or nine alphabets taken on each subject were thrown out in making Tables IV and V by way of allowance for practice.

---

p. 410. By an error of the draughtsman the ordinates of the curves for H are too short by four spaces and those of the curves for J by two. The curves in the lower diagram are those for B and M with the letters from *Mind*.

p. 418. The letters in the cut indicate parts as follows: *a* the pendulum, *b* the large cogwheel attached to it, *c* and *c′* the notched cardboard disks, *d* and *d′* the free brass disks clamping the last in place. In Fig. II *e* and *e′* are the two-and-a-half-inch gears, and *f* is the third disk which moves at the same angular rate as the pendulum. One of the mirrors is to be seen inclining forward above and behind the cardboard disks. Fig. I represents the machine ready for the fall of the pendulum.